LEVEL 2 SPRINGS INVENTORY OF THE ESCALANTE RIVER HEADWATERS AREA, GRAND STAIRCASE-ESCALANTE NATIONAL MONUMENT

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Executive Summary

In June 2006, a set of seven springs and one well were inventoried within the Bureau of Land Management Grand Staircase-Escalante National Monument in accordance with protocols developed jointly by representatives at Northern Arizona University and the National Park Service. Inventories included descriptions of the site, water quality, and discharge as well as collection of water samples for laboratory analysis. The sites were selected to provide information on the source and behavior of groundwater in the area around tributaries at the headwaters of the Escalante River. All of the sites inventoried discharged from the Navajo Sandstone, the predominant geologic unit in the study area.

The majority of the inventoried locations had little to no anthropogenic disturbance. Site elevations ranged from 1,618 to 1,873 meters, and site sizes ranged from tens of square meters to over a hectare (10,000m^2). Many of the spring locations were actually complexes of springs rather than singular orifices. Five springs were hanging garden-type and two were rheocrene-type. Discharges ranged from 44.86 liters per second at the Upper Calf Creek spring complex to 0.079 L/s at the Deer Creek spring.

Geochemical analyses point to a high elevation/winter precipitation recharge source, the Boulder Mountain area to the north of the study area. Isotopic data ($\delta^{18}O$, δ^2H, and ^3H) point to variations in groundwater flow paths and amount of groundwater mixing between the high elevation/winter recharge water and lower elevation/warmer recharge water. Evidence indicates that the higher elevation benches and mesas extending south into the study area are the primary pathways of groundwater from the Boulder Mountain region. Water chemistry is often more similar on either side of these drainage divides than on either side of the drainages themselves.

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Introduction

The Escalante Canyons region of Grand Staircase-Escalante National Monument (GSENM) is typified by a semi-arid climate. Even so, the area contains several perennial tributaries which supply the Escalante River. Most of these creeks are groundwater-derived from the thick sedimentary aquifers of the Escalante region, primarily the Jurassic Navajo Sandstone. The Navajo Sandstone provides the baseflow to several tributaries (Pine, Mamie, Calf, Boulder, and Deer Creeks) in the headwaters region of the Escalante River. These tributaries provide the majority of the baseflow of the Escalante River along its entire 80-mile reach between Escalante, UT and its discharge into Lake Powell (Wilberg and Stolp, 2004).

The Navajo Sandstone aquifer system in the Escalante region and the tributary canyons to which it provides baseflow is not well understood. Much of the recharge to the aquifer occurs in the high elevations of Boulder Mountain to the north and the generally thick, well sorted eolian sandstone of the Navajo acts as a large reservoir and conduit for this recharge. Boulder Mountain is composed of primarily volcanics and volcanic-derived colluvium overlying the Carmel Formation and the Page and Navajo Sandstones. Snow and rains in this area infiltrate through porous media and fractures to recharge the Navajo Sandstone below. To better quantify the relationships between recharge area/season, residence time within the aquifer, flow paths, and amount of aquifer mixing, an inventory of eight locations (7 springs and one well) within tributaries of the Escalante River headwaters (Sand, Calf, Boulder, and Deer Creeks) was conducted. The hypothesis was that springs could provide insight into the behavior and mechanics of the aquifer system supplying them. Physical and geochemical data from each of these eight locations were gathered and an investigation was made into the nature and behavior of groundwater between its source area and eventual discharge from the groundwater system. Physical data such as discharge rate and water-quality parameters including pH, specific conductance, and dissolved oxygen content were collected in the field, and several water samples at each location were collected for laboratory analysis. Geochemical analyses, including stable (^{18}O and ^{2}H) and radiogenic (^{3}H) isotopes, coupled with physical data provided information about the aquifer system that provides much of the groundwater and surface water to the Escalante River within GSENM.

Methods

Inventories conducted at the eight specified locations followed the protocols developed by Northern Arizona University for the Inventory and Monitoring Network of the National Park Service through cooperative agreement (CA 1200-99-009 Task #NAU-117) (Springer and others 2005). Specific processes for site description, water quality, discharge, and sample collection were followed in accordance with protocols developed in this cooperative agreement. Selection of the spring inventory sites was made jointly by NAU and BLM staff. These selections were based on a need to have a spatial distribution of springs wide enough to cover the extent of several of the Escalante River tributaries within the GSENM, but to be grouped closely enough that useful relationships could be generated (Figure 1, Table 1). All eight of the inventoried locations discharged from the Jurassic Navajo Sandstone, the predominant geologic unit in the study area.

Using the field forms developed by Springer and others (2005), data were collected at each of the eight inventory sites. A site description was conducted, with information on site elevation, geomorphic character, slope, aspect, size, condition, and evidence of use and/or disturbance (Table 2). Photos were taken to supplement the written descriptions. Information was gathered on the geologic unit from which the spring was discharging, as well as any other geologic features in the area that may have had some effect on the spring itself (Table 2). The emergence environment, force flowing mechanisms, and the orifice/spring type were described (Table 2). Spring discharge was measured with the method most appropriate for the conditions at each site. Depending on the rate of discharge and the emergence environment, a volumetric container, weir plate (45°), or flume was used. If discharge emerged from several orifices at the site and coalesced into one channel, the combined flow was measured or estimated. If the discharges remained separate, measurements were made at each orifice and a combined discharge was calculated.

Water-quality parameters were collected on-site using a Troll 9000 multi-parameter water-quality probe (In-Situ Corp., Ft. Collins, CO). Measurements of water temperature, pH, conductivity, and dissolved oxygen content were collected simultaneously. Water samples were collected for laboratory analysis. Major cations and anions, alkalinity, total dissolved solids (TDS), nutrients (nitrate, nitrite, and phosphate) and both stable (^{18}O and ^{2}H) and radiogenic (^{3}H (tritium)) isotopes were analyzed from each of the inventoried locations. Tritium samples were analyzed by the Laboratory of Isotope Geochemistry at the University of Arizona. The remainder of the analytical work was completed by the Colorado Plateau Stable Isotope Laboratory at NAU.

Cation and anion data were plotted on Piper and Stiff diagrams using Rockworks2002 (Rockware, Inc., Golden, CO). The Piper diagram is a form of trilinear diagram with two triangular plots on either side of a 4-sided "diamond" center plot. The sides of the triangles run from 0 to 100 representing the cation (left) and anion (right) concentrations (milliequivalents). Data points in the diamond center plot are located by extending the points in the lower triangles to the corresponding location in the center plot. The Stiff diagram plotting technique uses four parallel horizontal axes extending on each side of a vertical zero axis. Concentrations of four cations (Ca, Na+K, and Mg) are plotted to the left of the zero axis, and four anion combinations (Cl, CO_3+HCO_3, and SO_4) are plotted to the right of the zero axis. The resulting plot is a good indicator of basic water quality and comparison of similar and dissimilar waters.

TDS was plotted against conductivity values measured in the field to quantify a relationship that will assist in estimating TDS concentrations based on field-measured conductivity.

$\delta^{18}O$ and $\delta^{2}H$ values were plotted against Standard Mean Ocean Water (SMOW) and two local water lines representing precipitation at the South Rim of the Grand Canyon (Monroe and others, 2005) and for a series of spring water samples collected on the Colorado Plateau in 2005 (Springer, et al., 2006). The $\delta^{18}O$ and $\delta^{2}H$ values reported in this text and in the figures represent the average value of two analytical runs.

Tritium data were used to determine the relative age of the spring water. The results allow for qualitative, not quantitative estimates of groundwater age. Tritium is continually generated in the upper atmosphere as a result of cosmic radiation. The base level of tritium content in the atmosphere (and consequently rainwater) increased exponentially during testing of thermonuclear devices between 1955 and 1975 (up to 1000 TU) (Eastoe, 2006). The half-life of tritium is approximately 12.4 years, so relative ages can be estimated based on the presence of tritium as well as the concentration based on the known decay rate (Moran and Hudson, 2005). Tritium in waters precipitated before nuclear testing would have now decayed below laboratory detection limits (0.6 TU). Recent rainwater has tritium concentrations of approximately 5-6 TU (Eastoe, 2006).

Results

Field Data

The eight sites inventoried for this study ranged in elevation from 1,618 to 1,873 meters (5,307 to 6,143 feet) above mean sea level. Site areas were reported in accordance with the NPS field forms (Springer and others 2005) and were categorized as one of several area ranges. The majority of the springs sites inventoried were between 10 and 1000 m^2. Site area was difficult to consistently measure because most of the locations are a system of springs rather than singular orifices. The average site slope was 20.4 degrees, but five of seven spring locations had site slopes of five degrees or less. The average was increased by two steeply-inclined sites (Lower Calf Creek Falls and Deer Creek springs). Site aspects ranged from 35 to 180 degrees, with an average of approximately 103 degrees. Five of the seven springs inventoried were hanging garden-type springs which emerge as a linear array of seeps or drips along contacts between or within geologic units. The presence of these contact springs are often a result of variations in the bedding planes of the eolian deposits of the Navajo Sandstone. Areas with potentially higher silt content such as inter-dune areas between cross-bed sets or the lee sides of dune faces can preferentially locate spring emergence areas (e.g., May et al., 1995). Two of the seven springs were classified as rheochrene springs (Willow Patch and Dry Hollow), which emerge as flowing streams from the orifice. One hanging garden spring (Deer Creek) and one rheochrene spring (Willow Patch) were formed because of fractures located in the bedrock. This distinguishes them from the remainder of the springs which are considered contact springs. All of the inventoried springs emerged subaerially (above ground) and all spring flow was assumed to be gravity-forced (rather than artesian pressure).

In a stark contrast to many of other springs inventoried on the Colorado Plateau (Springer, et al., 2006), the springs inventoried within the study area had minimal to no anthropogenic disturbances such as modifications to the orifice or channel to increase flow or modifications for livestock grazing. The Lower Calf Creek Falls spring location is a popular destination for hikers, but the attraction is the waterfall and there is little evidence of disturbance to the spring systems. The Sand Creek Shower spring has a campsite nearby and is known as a stop for hikers along the Escalante River trail for drinking water and a shower (hence the name). Disturbance to the spring location itself, however, was minimal. The Deer Creek spring is located on private property and is near several irrigated fields and old home sites, but the spring itself had very little evident impact. The remainder of the springs were characterized as “pristine” and had no evidence of disturbance, mostly due to their remote locations.

Discharge rates of the inventoried springs were highly variable (Table 3). It is difficult to compare locations, as a distinction must be made between single orifices and spring complexes. The Upper Calf Creek spring complex, for example, gains from springs in two distinct tributaries, one of which has an approximately 500m-long seeping wall complex. Discharge rates ranged from 44.86 liters per second (L/s) (712 gallons per minute) for the Upper Calf Creek headwaters spring complex to 0.079 L/s (1.253 gpm) at the Deer Creek spring. A stabilized pumping rate of 0.000059 L/s (.00094 gpm) was achieved from the Deer Creek floodplain well (MW-1), but this should not be confused with a spring discharge rate.

Water-quality parameters of temperature, pH, conductivity, and dissolved oxygen were measured at each of the inventory sites (Table 4). Water temperatures ranged from 11.9 to 15.9 °C. Five of the eight sampled locations had a relatively neutral pH (6.0-8.0). Three samples were considered moderately basic (pH>8.0). The average pH value was 7.94. Dissolved oxygen content of the sampled sites ranged from 1.58 mg/L to 8.1 mg/L, with an average value of 6.42 mg/L. Conductivity values ranged from 122 μS/cm (Deer Creek Spring) to 726 μS/cm (Sand Creek Shower Spring). Conductivity values were compared to TDS values from the analytical results to develop a relationship between the two values. TDS values ranged from 100 mg/L (Deer Creek Spring) to 530 mg/L (Sand Creek Shower Spring) which mimics the pattern seen in the conductivity results. A linear regression between conductivity and TDS was developed with an equation of TDS=0.713 x Conductivity + 53.5 with an R^2 value of 0.81, making this relationship a relatively useful tool in the study area for field estimating TDS based on conductivity values (Figure 3). Besides the Sand Creek Spring value, all of the sampled locations had TDS concentrations below 500 mg/L, which is the secondary standard for drinking water developed by the U.S. Environmental Protection Agency (EPA).

Geochemical Analyses

Piper and Stiff diagrams (Figures 4 and 5) were created for the cation and anion data (Table 5). Most of the water was of the calcium-sodium, bicarbonate type. Outliers included Sand Creek Shower spring, which had highly elevated chloride content, and Upper Calf Creek spring, which had a moderately elevated chloride and sulfate content in comparison to the other waters.

Data for $\delta^{18}O$ and $\delta^{2}H$ were plotted against three standard lines, one representing standard ocean water, one representing meteoric water at the South Rim of the Grand Canyon (Monroe and others, 2005), and one representing values from a set of springs on the Colorado Plateau collected in 2005 (Springer, et al., 2006) (Figure 6). The data points for the Escalante samples scatter closer to the Colorado Plateau spring water line than the other two lines. The probable cause is that stable isotopes in discharging groundwater reflect effects of the partial fractionalization that occurs as a result of water-rock interactions along flow paths. Therefore the Escalante spring water samples would plot closer to this line than one representing ocean or meteoric waters that would have little or no water-rock fractionalization influence. Additionally, many of the springs sampled during the Colorado Plateau inventory of 2005 were in the vicinity of the study area, and include the National Parks/Monuments/Recreation Areas Bryce Canyon, Zion, Cedar Breaks, Capitol Reef, Canyonlands, and Glen Canyon, and therefore may share relatively similar geochemical properties.

The relation between stable isotope concentration and elevation was investigated and it was found that there is no correlation between the elevation of the spring orifice and either $\delta^{18}O$ or $\delta^{2}H$ (R^2 average value 0.069) (Figures 7 and 8). A relation between discharge and $\delta^{18}O$ or $\delta^{2}H$ values has been seen in studies of springs in other areas, but due to the nature of the investigated springs being systems of springs rather than single-point discharges, this relation could not be investigated reliably for the Escalante samples. The data table (Table 6) reports the values for each of the runs as well as the averaged values. $\delta^{18}O$ values ranged from -14.16 to -12.18‰, and $\delta^{2}H$ values ranged from -91.2 to -106.5‰. Generally, winter/high elevation precipitation (especially snow) is more depleted in ^{18}O and ^{2}H than is summer/low elevation precipitation. The more depleted the sample is, the higher the percentage of winter/high elevation recharge the spring water is assumed to have.

While $\delta^{18}O$ and $\delta^{2}H$ values assist in interpreting source location, season, and elevation, tritium (^{3}H) values give an idea of the relative age of the groundwater at the discharge point. Results are reported in tritium units (TU) where 1 TU represents 1 atom of tritium per 10^{18} atoms of hydrogen (Table 6). Tritium values in this study ranged from 0.3 TU to 5.4 TU. Current amounts of tritium in rainwater in the southwest are between 5 and 7 TU (Eastoe, et al., 2004).

Interpretations/Conclusions

Overall Interpretations

The cation and anion data presented in the Piper and Stiff diagrams as well as in Table 5 show relatively similar trends barring the outlier concentrations of chloride in the Sand Creek Shower sample and chloride and sulfate in the Upper Calf Creek sample. These similarities are consistent with a set of springs in relatively close proximity, discharging from the same source rock, and sharing a similar recharge area. The $\delta^{18}O$ and $\delta^{2}H$ values are the most important indicators of the source of the spring water at the inventoried sites. The $\delta^{18}O/\delta^{2}H$ plot (Figure 6) shows that most of the spring locations are quite depleted and represent a predominantly winter/high elevation recharge source. Sand Creek Shower, Lower Calf Creek 2 (west side of creek), and Upper Calf Creek springs were grouped together as the most depleted of the set sampled, and therefore derive most of their discharge from winter/high elevation sources.

Tritium concentrations do not have a pattern that would be expected from an area where the majority of recharge water originates from one location. If all groundwater flowed in a generally similar direction at a similar rate, tritium concentrations would be expected to increase away from the recharge area as recharge water precipitated at the height of atmospheric tritium concentration migrated downgradient. Concentrations would then decrease to zero as distance increased from the recharge area and water in the aquifer system was older than the input of nuclear-generated tritium and the amount of natural atmospheric tritium had decayed. The fact that this pattern does not exist supports the hypothesis that there are variations in flow path lengths and differences in the hydraulic conductivity of the Navajo Sandstone in the study area. Variability of this sort was observed when groundwater residence times were calculated for springs discharging from the Navajo Sandstone at Zion NP (Kimball and Christensen, 1996).

It is apparent that canyon-cutting due to overland flow erosion and groundwater sapping in the Escalante River headwaters region is the overriding cause of the location of the springs feeding the tributaries to the Escalante, and may also cause deflection of flow paths of the groundwater being recharged from the high elevations to the north. The cause of the canyons themselves, however, is beyond the scope of this investigation. A lineament and fault analysis of the region would assist in investigating potential regional structural controls on the location and orientation of the canyons in the area. If the canyons in the study area are the locations where groundwater discharges into the Escalante River's tributaries, the un-dissected mesas and benches in the study area may act as pathways to move groundwater from the higher elevations towards the Escalante River before being intersected by canyon cutting. Prominent features such as the benches of Slickrock Saddle, McGath Point, and New Home, and Durffey Mesa may also play a significant role in the flow paths of groundwater in the study area.

Calf Creek Springs

Calf Creek is the only one of the Escalante River tributaries studied that does not have its headwaters in the volcanics/colluvium/sandstone of the higher elevations north of the study area. The baseflow for Calf Creek is derived entirely from Navajo Sandstone spring discharge within GSENM. The stable and radiogenic isotope as well as the cation and anion data for the three samples collected in this tributary (Upper Calf, Lower Calf 1 (east) and 2 (west)) point to heterogeneous flow path length and/or hydraulic conductivity as well as level of groundwater mixing depending on which side of the Calf Creek drainage the spring discharges from.

Upper Calf Creek spring is located close to the high elevation recharge area on the volcanic-capped Boulder Mountain in the neighboring Dixie National Forest. $\delta^{18}O$ and $\delta^{2}H$

values (-13.67 and -105.7‰, respectively) indicate a strong influence of recharge water from Boulder Mountain to the north. Tritium concentration (2.8 TU) indicates relatively young water, with the concentration similar to approximately one tritium half-life based on current meteoric concentrations. The two samples from the Lower Calf Creek Falls springs have interesting results. Lower Calf Creek (1) was collected from the east side of the Calf Creek drainage, while Lower Calf Creek (2) was collected from the west side of the drainage. The two sides differ significantly in virtually every field measurement and laboratory analysis. $\delta^{18}O$ and $\delta^{2}H$ data for the two sides indicate that the west side of the drainage has a distinctly more depleted signature than the east side. Similar results are seen in the $\delta^{18}O$ and $\delta^{2}H$ results from Upper Calf Creek spring, which also discharges from the west side of the drainage. The two sides also have a difference in tritium concentration, with the sample collected from the west side having the lowest tritium concentration of all the locations sampled at and estimated 0.3 TU. This concentration was estimated as it was below the laboratory detection limits of 0.6 TU. This tritium value would therefore represent the oldest water collected in this study. The sample from the east side of the drainage had a tritium concentration of 0.9 TU. The differences in these geochemical data as well as other field water-quality parameter and cation/anion data differences between these two locations point strongly to different flow paths in the area between McGath Point Bench and New Home Bench, which border the Calf Creek drainage on the west and east, respectively.

Sand Creek Shower Spring

The Sand Creek Shower spring sample was by far the most distant from the suspected recharge area, as the spring is just a few hundred meters north of the confluence of Sand Creek and the Escalante River, and is also the lowest elevation. This spring was also the most depleted in $\delta^{18}O$ and $\delta^{2}H$, indicating that this spring has the highest proportion of high elevation/winter precipitation recharge of the locations sampled. Relatively un-dissected terrain (compared to the rest of the study area) along the presumed flow path between Boulder Mountain and this spring may allow this water to travel further south before being discharged. In other words, the higher elevations of the Slickrock Saddle Bench extend further south than the area to the east, where the other samples were collected (see Figure 2), allowing groundwater to flow further south without discharging in canyons further north. Tritium was measured at 1.4 TU for the Sand Creek spring. Besides the concentration of the sample from Willow Patch spring, which will be discussed later, only the sample from Upper Calf Creek (close to the recharge area) had a higher tritium concentration. This result points to one of two scenarios. First, the flow path from the recharge area to the spring could be relatively rapid in comparison to others in the area, for this spring is the longest surface distance from the recharge area. Second, some amount of mixing with more recent groundwater could be occurring which is elevating the tritium concentration in the spring water. Of these two scenarios, the first seems more plausible, based on the $\delta^{18}O$ and $\delta^{2}H$ data. Sand Creek Shower Spring is the most depleted in $\delta^{18}O$ and $\delta^{2}H$ of all the studied springs. If groundwater mixing were occurring, it is probable that it would be mixing with waters that were less depleted, ultimately skewing the $\delta^{18}O/\delta^{2}H$ plot in the positive direction.

The location of the spring itself is presumed to be influenced by a low hydraulic conductivity lens which may have relatively high silt content. The linear orientation of the spring and the productive discharge distinguish it from several of the other hanging garden type springs visited that often discharge from a thick zone along a wall and seep rather than discharge from one level as sheet flow. The elevated TDS (530 mg/L) and especially conductivity (726 µS/cm) values are dissimilar to all other sampled sites, and support the interpretation that the groundwater has traveled along or has interacted with a material of different geologic composition than the other samples.

Dry Hollow Spring

Dry Hollow spring is located near the upper reaches of Dry Hollow canyon, which is an intermittent tributary of Boulder Creek. $\delta^{18}O$ and $\delta^{2}H$ data plot well below the line representing spring water on the Colorado Plateau. Given that this spring emerges from sand in the drainage rather directly from the bedrock, the position on the plot may be a signature of some evaporation occurring between discharge from the bedrock and discharge from the sand. A tritium concentration of 0.9 TU is the same as the sample from Lower Calf Creek (1), which is farther south but is on the end of the same drainage divide, New Home Bench. In fact, the two locations had very similar pH and temperatures, and identical values for both TDS (160 mg/L) and Alkalinity (154 mg HCO_3/L). These data may suggest a similar flow path supplying groundwater to the two springs. With a discharge rate of 0.292 L/s (4.63 gpm), this spring has little influence on the total input of the studied tributaries of the Escalante River.

Willow Patch Spring

Willow Patch Canyon is a tributary of Sand Creek and enters from the east. Willow Patch Spring was located near the upstream end of the groundwater-fed riparian/wetland area within the canyon. The spring itself provided very little (0.063 L/s, or 1.0 gpm) flow in comparison to the complex of spring discharge that was measured down-channel at 3.16 L/s (50.2 gpm). The spring source was described as a fracture feature, with the fracture more vertical than horizontal. The $\delta^{18}O$ and $\delta^{2}H$ values (-12.23 and -91.2 ‰, respectively) were the least depleted (highest values) of all of the locations sampled. Additionally, the tritium concentration was much higher than any of the other sampled sites, at 5.4 TU. The high tritium concentration is very similar to recent rainwater, and the spring's proximity to the vertical fracture feature in the canyon suggests that the fracture is acting as a conduit for local recharge to enter the spring system, providing the elevated tritium concentrations as well as the high $\delta^{18}O$ and $\delta^{2}H$ values from partial mixing of lower elevation-sourced recharge. Based on the implied fracture influence at this spring location, the data is assumed to be not representative of aquifer at that location which is supplying water to the remainder of the spring system in Willow Patch canyon and eventually to Sand Creek.

Deer Creek Spring/Floodplain Well

The Deer Creek Spring discharges from a wall along the west bank of Deer Creek. The spring emergence is a combination of a bedding plane hanging garden as well as a fracture feature. The fracture runs horizontally parallel to, and is presumed to be influenced by, bedding planes in the Navajo Sandstone. The water issuing from the fracture provides the majority of the discharge at this location. The $\delta^{18}O$ value of -12.18 ‰ is actually less depleted than the Willow Patch Spring sample, but the $\delta^{2}H$ value of -97.2 ‰ is significantly more depleted than the Willow Patch sample. The water sample had a tritium content of 0.8 TU, which is similar to the concentration seen in Dry Hollow as well as that seen in Lower Calf Creek (1). The Deer Creek spring sample was the only one that had a nitrate (NO_3) concentration of over 1.0 mg Nitrogen per Liter (N/L) (1.03). This spring was the only inventoried location that was on private property. Evidence of irrigation on the property and in the surrounding area may have enhanced local recharge in this area and percolated higher nitrate concentrations into the aquifer. This supports an existing hypothesis that there may be a "dome of recharge" in the area around the Town of Boulder from irrigation-sourced infiltration.

The Deer Creek floodplain well (MW-1) was the only non-spring location sampled during the inventory. This shallow (8.2 feet) well was completed in recent alluvium in the Deer Creek floodplain (it extends to, but does not penetrate, the contact with the underlying Navajo Sandstone), and the water had traveled from its presumed bedrock source to the sampling point. The stable isotopes plotted near the center of the eight samples, and almost directly on the 2005 Colorado Plateau springs line (-12.88 and -99.3‰ $\delta^{18}O$ and $\delta^{2}H$, respectively). The sample was collected using a peristaltic pump. Water quality parameters were measured during pumping until the parameters stabilized and the discharge was considered to be representative of the water in the aquifer rather than the well casing and surrounding filter pack. This location had a low (<0.5 TU) tritium concentration in comparison to most of the rest of the samples analyzed. The stable isotope data point to a potential mixing of Navajo Sandstone derived groundwater with percolated rainwater and perhaps even Deer Creek high-flow/flood water (although the second scenario is unlikely given the known bedrock topography variations in the area), but the tritium concentrations indicate very little to any recent water interactions. A comparison with data from the Deer Creek Spring, the closest sampled spring to the well, show that the well sample is isotopically lighter than the spring sample, is apparently older (based on tritium concentration), and had higher concentrations of most cation and anion components. The differences suggest potential flow path and/or hydraulic conductivity differences between the two areas, although the two locations share the same discharge basin. The Deer Creek well sample displays signatures of a slower flow path in the lower tritium concentration in comparison to the Deer Creek spring sample. The more negative stable isotope values also indicate a higher concentration of high elevation/winter precipitation recharge than the spring sample. The effect of the bedrock fractures at the Deer Creek spring location may result in a faster and more localized flow path, which is supported by the higher tritium concentration and more positive stable isotope values in comparison to the well sample.

Conclusions/Recommendations

The headwaters of the Escalante River are defined by the input of groundwater into several tributaries, including Sand, Calf, Boulder, and Deer Creeks. The source of this groundwater is the Jurassic Navajo Sandstone, the predominant geologic unit in the study area. Although often described as rather homogeneous, well-sorted eolian sandstone, physical and geochemical evidence point to differences in the transmissivity of this water-bearing unit within the GSENM study area. Based on the results of eight locations inventoried and sampled (7 springs and one well), variations in source location, relative age, and degree of groundwater mixing were identified in the area of these tributaries of the Escalante River. Groundwater discharge from different sides of a drainage divide may be more similar to those from different sides of the same drainage due to flow path differences around existing incised canyons.

The assumptions and interpretations presented in this report are based on single data points for all physical and geochemical parameters discussed. To increase the validity and quality of the results, it is suggested that additional data be collected. Data collected from the other two major tributaries to the Escalante River, Pine and Mamie Creeks, would assist in drawing similar conclusions to ones developed in the study area and therefore support the findings in this report. Winter precipitation geochemical data from the assumed Boulder Mountain recharge area would assist in confirming the source area and better constrain the amount of groundwater mixing occurring between the recharge area and spring orifice. Additionally, in areas where trends are seen along a flow path or on different sides of a drainage, as is seen with the Calf Creek samples, it would be beneficial to collect samples from springs discharging from both sides of the gaining reach between the Upper and Lower Calf Creek falls to confirm or dispute the relationships seen in this report. Finally, the fact that the samples collected for this study are from one time period, relationships and influences based on seasonal differences may not be recognized. In addition to expanding the spatial scope of the investigation, it would be important to expand it temporally as well.

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Figure 1. Geology and major tributaries in the GSENM study area

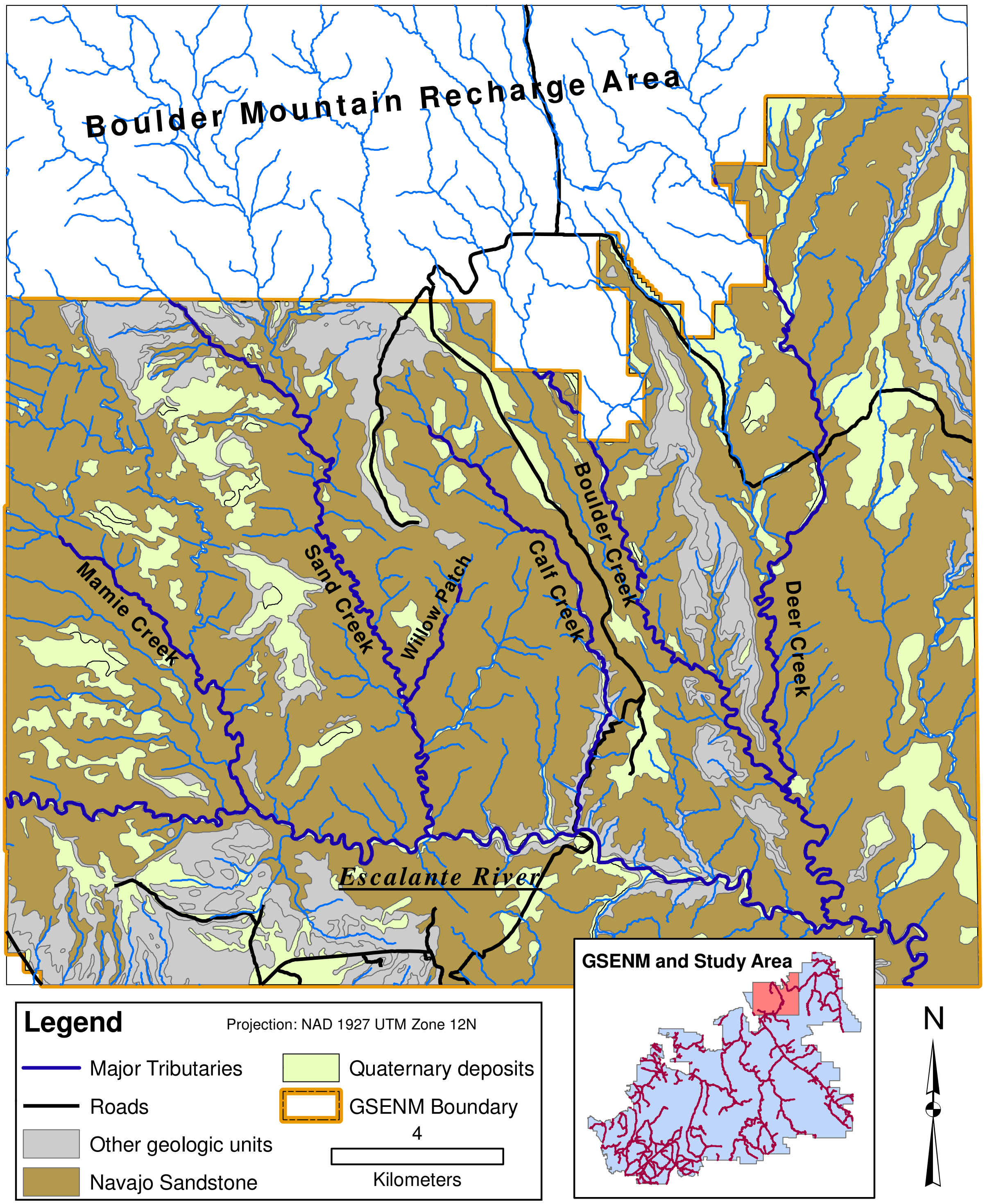

Figure 2. Sample collection sites and elevation shading in the GSENM study area

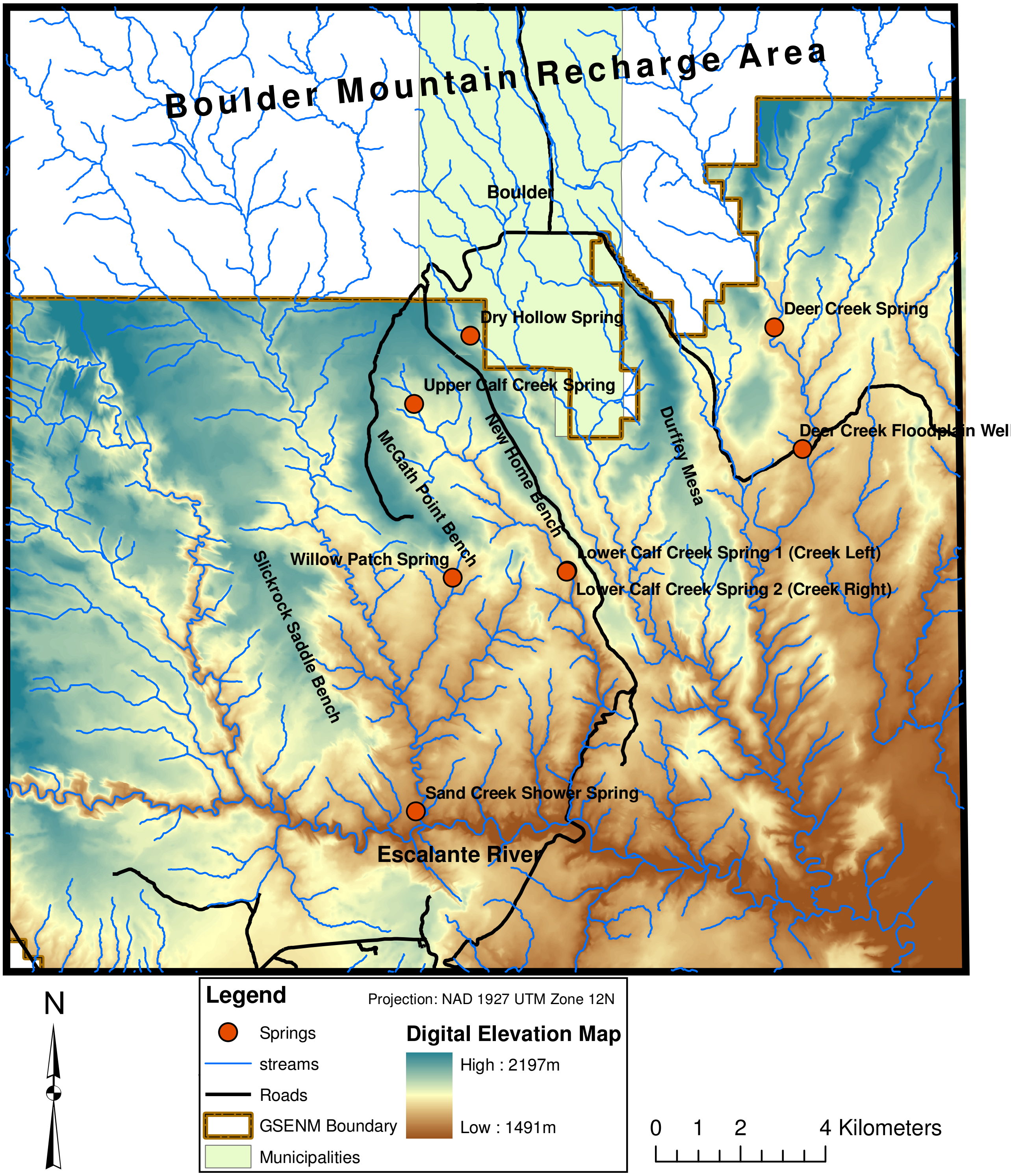

Figure 3
Plot of relationship between TDS and conductivity
Escalante Basin groundwater samples

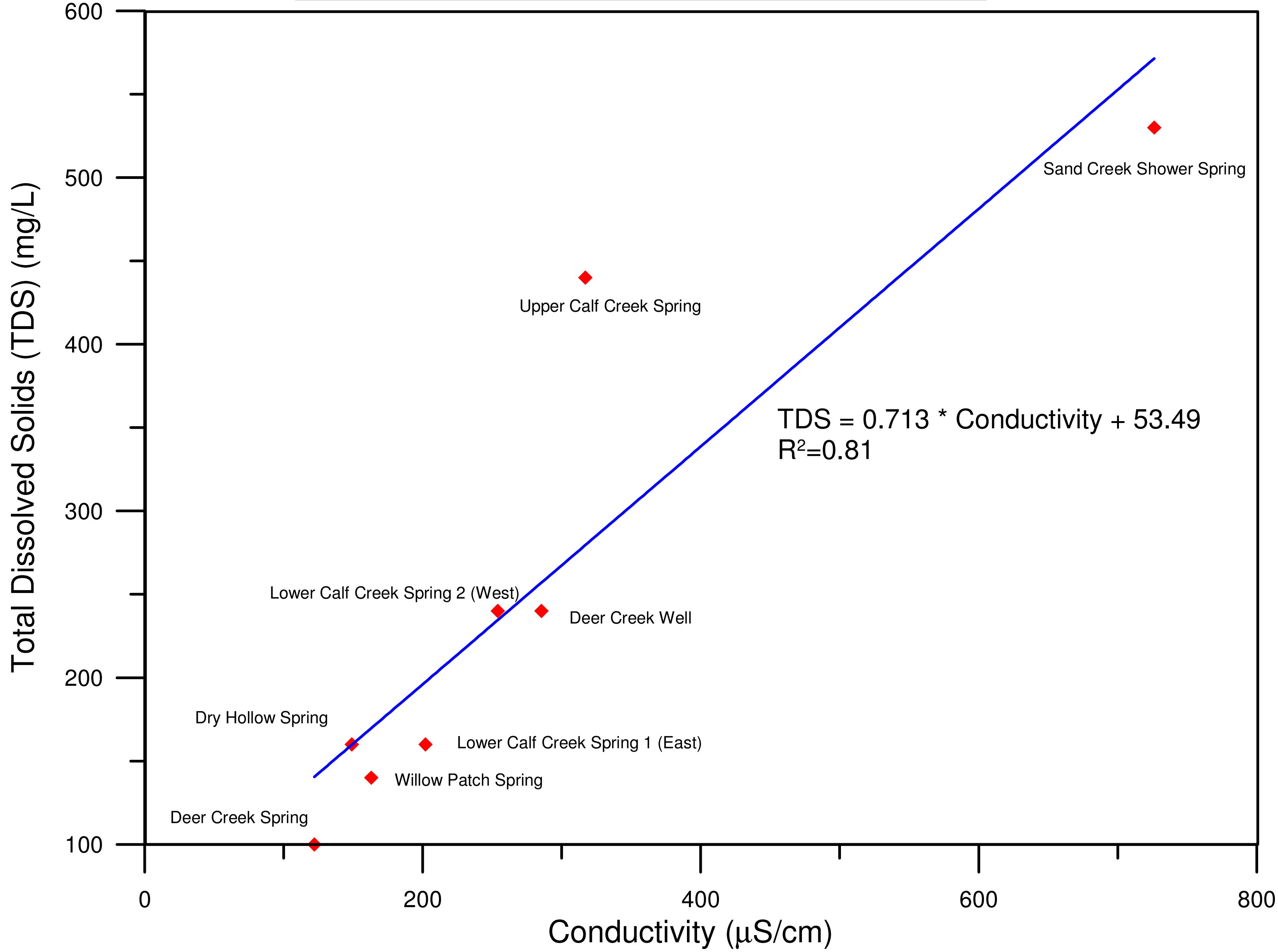

Figure 4. Piper diagram of Escalante Basin groundwater samples

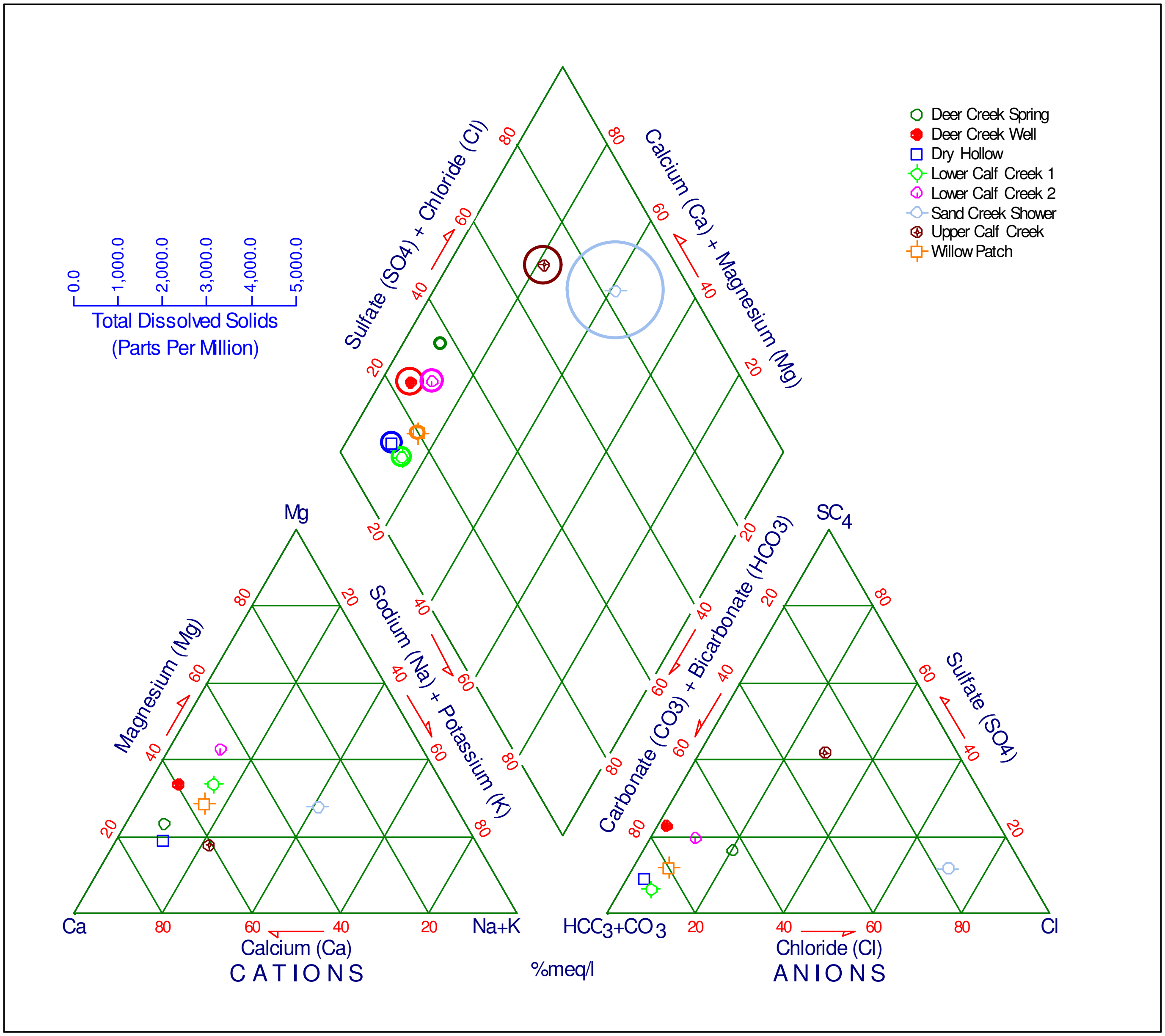

Figure 5. Stiff diagrams of Escalante Basin groundwater samples

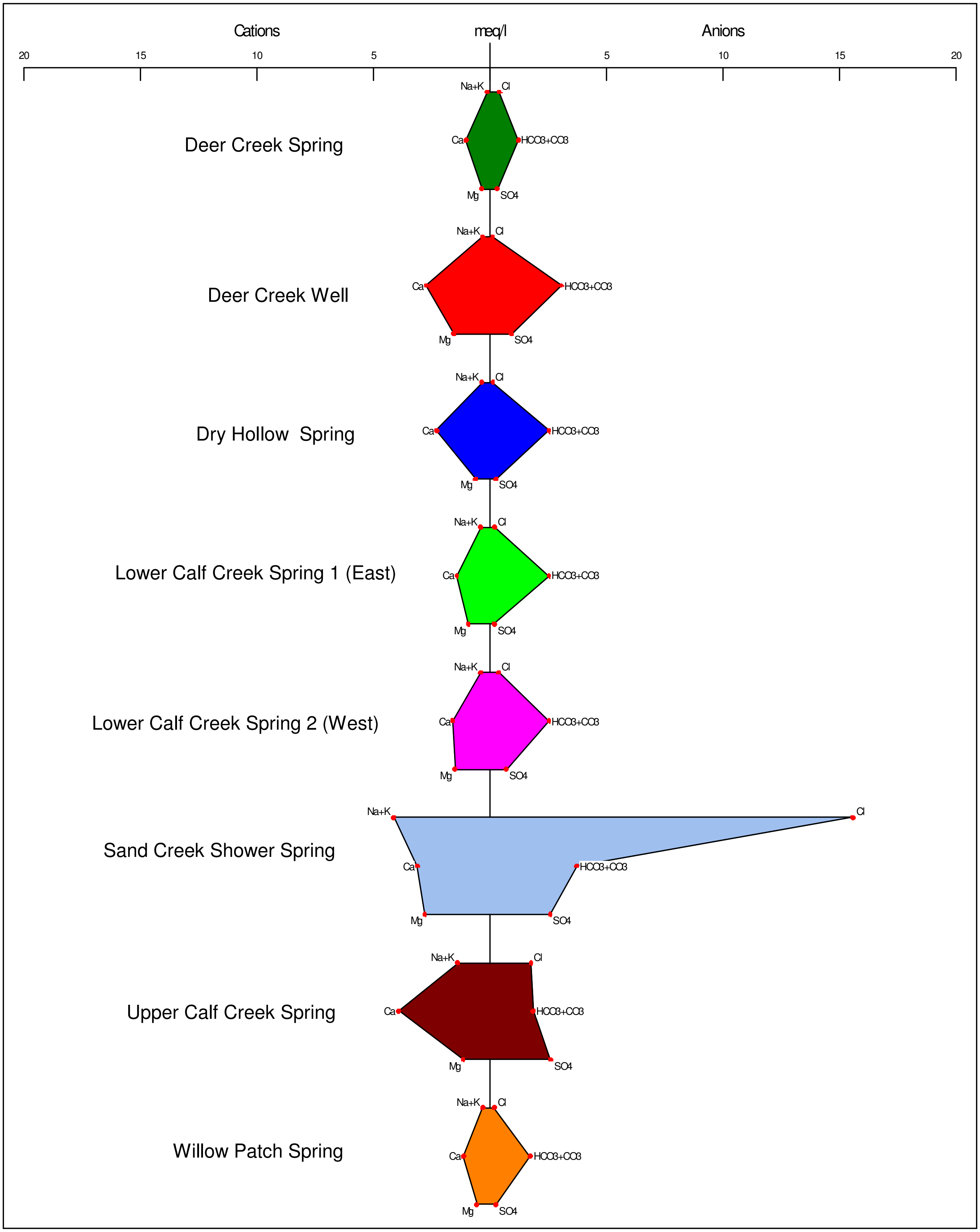

Figure 6
Oxygen / Hydrogen isotope analysis of
Escalante Basin groundwater samples
plotted against oceanic, meteoric and spring water lines

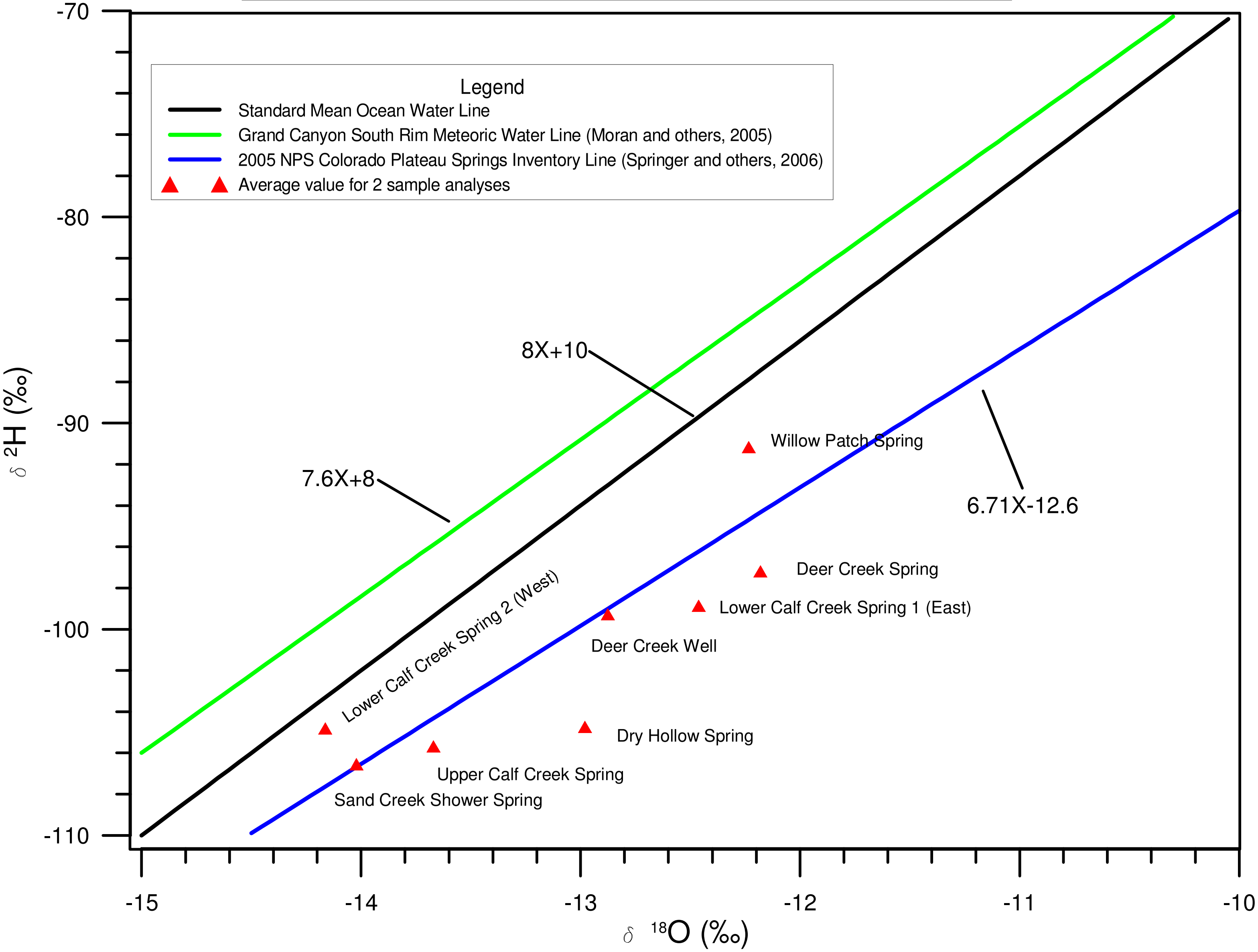

Figure 7
Oxygen-18 concentration vs. elevation
Escalante Basin groundwater samples

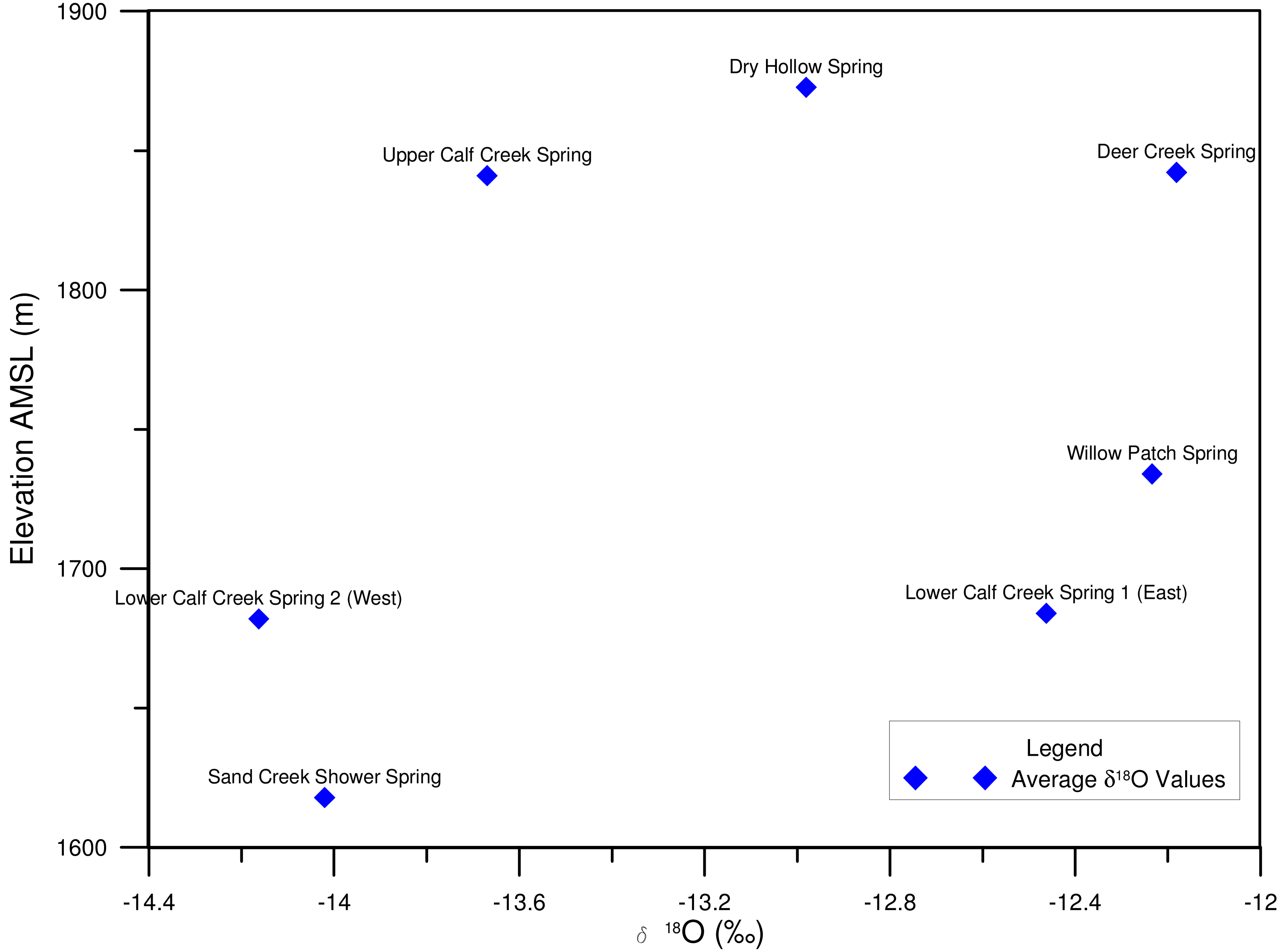

Figure 8
Deuterium concentration vs. elevation
Escalante Basin groundwater samples

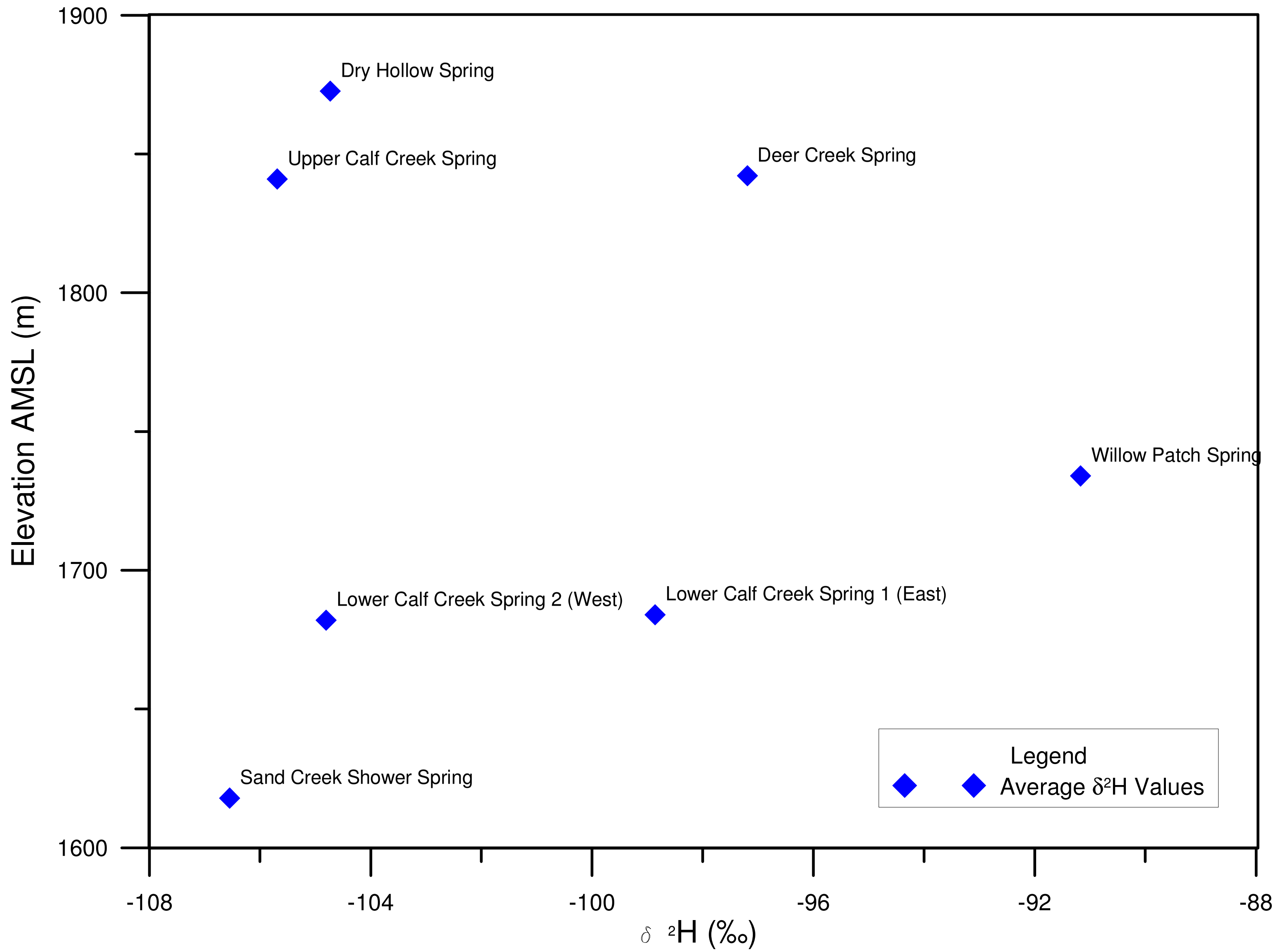

Table 1
Location Data for Inventoried Springs and Well

Location Name	UTM NAD 27 N	UTM NAD 27 E	Source	Error (m)	Elev. (m)	Elev. (ft)
Upper Calf Creek Spring	4190671	459533	GPS	10	1841	6040
Lower Calf Creek Spring 1 (East)	4186730.6	463149.06	DRG	unknown	1684	5525
Lower Calf Creek Spring 2 (West)	4186711.75	463128.35	DRG	unknown	1682	5519
Sand Creek Shower Spring	4181051	459580	GPS	35	1618	5308
Willow Patch Spring	4186568	460440	GPS	unknown	1734	5689
Dry Hollow Spring	4192283	460867	GPS	15	1873	6144
Deer Creek Spring	4192479	468026	GPS	20	1842	6044
Deer Creek Floodplain Well	4189609.675	468693.8396	BLM Survey	unknown	1744	5720

Table 2
Site Description Summary

Location Name	Slope	Aspect	Site Area	Spring Type	Emergence Substrate	Orifices
Upper Calf Creek Spring	2°	55°	.1 - 1 ha	Hanging Garden	Bedrock (Navajo SS)	Multiple
Lower Calf Creek Spring 1 (East)	50°	180°	100-1000 m^2	Hanging Garden	Bedrock (Navajo SS)	Multiple
Lower Calf Creek Spring 2 (West)	5°	90°	100-1000 m^2	Hanging Garden	Bedrock (Navajo SS)	Multiple
Sand Creek Shower Spring	2°	35°	10-100 m^2	Hanging Garden	Bedrock (Navajo SS)	Multiple
Willow Patch Spring	2°	90°	10-100 m^2	Rheochrene	Sand	Single
Dry Hollow Spring	2°	180°	100-1000 m^2	Rheochrene	Sand	Multiple
Deer Creek Spring	80°	90°	100-1000 m^2	Hanging Garden	Bedrock (Navajo SS)	Multiple
Deer Creek Floodplain Well	NA	NA	NA	NA	NA	NA

Table 3
Discharge Data for Inventoried Springs and Well

Location Name	Discharge (gpm)	Discharge (L/s)
Upper Calf Creek Spring Comlex (west fork before confluence)	456	28.73
Upper Calf Creek (east fork upstream end of seep face near sample point)	37.2	2.34
Upper Calf Creek Complex (downstream end of east fork gaining reach)	256	16.13
Lower Calf Creek Spring 1 (East)	23.5	1.48
Lower Calf Creek Spring 2 (West)	13.4	0.844
Sand Creek Shower Spring	67.8	4.27
Willow Patch Spring	50.2	3.16
Dry Hollow Spring	4.63	0.292
Deer Creek Spring	1.253	0.079
Deer Creek Well	0.00094	0.000059

Discharge represents pumping rate from well, not spring discharge

Table 4
Field Water Quality Parameters for Inventoried Springs and Well

Sample Location Name	Sample Date	pH	Temp C	Cond (us/cm)	DO (mg/L)
Upper Calf Creek Spring	6/1/2006	7.15	13	317	6.2
Lower Calf Creek Spring 1 (East)	6/1/2006	7.4	11.9	149	7.32
Lower Calf Creek Spring 2 (West)	6/13/2006	8.7	15.9	254	7.7
Sand Creek Shower Spring	6/2/2006	8.1	14.3	726.3	8.1
Willow Patch Spring	6/11/2006	7.98	15	163	6.87
Dry Hollow Spring	6/12/2006	7.58	11.9	202	1.58
Deer Creek Spring	6/12/2006	8.65	14.2	122	6.5
Deer Creek Well	6/12/2006	7.95	15.8	285.4	7.11

Table 5
Cation and Anion Data for Inventoried Springs and Well

Sample Location	TDS (mg/L)	Alkalinity (mg HCO3/L)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	NO3 mg N/L	NO2 mg N/L	NH4 mg N/L	PO4 mg P/L
Upper Calf Creek Spring	440	113	14.0	78.4	29.5	4.4	62.3	125.0	0.09	<0.01	0.01	0.25
Lower Calf Creek Spring 1 (East)	160	154	11.3	28.6	8.3	1.8	7.1	8.8	0.14	<0.01	0.03	0.07
Lower Calf Creek Spring 2 (West)	240	154	18.3	32.0	8.3	1.8	13.1	33.9	0.10	<0.01	0.01	0.03
Sand Creek Shower Spring	530	227	34.0	62.5	91.0	7.0	550.8	123.9	0.16	<0.01	0.02	0.02
Willow Patch Spring	140	105	7.0	22.8	5.8	2.1	6.2	12.3	0.37	<0.01	0.02	0.11
Dry Hollow Spring	160	154	7.5	46.0	6.8	1.8	4.0	12.4	<0.01	<0.01	0.03	0.02
Deer Creek Spring	100	74	4.3	20.6	2.1	1.5	13.8	15.1	1.03	<0.01	0.02	0.07
Deer Creek Floodplain Well	240	186	18.8	54.8	5.6	2.7	3.1	44.3	0.02	<0.01	0.04	0.04

Table 6
Stable and Radiogenic Isotope Data from Inventoried Springs and Well

Spring Name	$\delta^{18}O$-run 1	δ18O-run 2	Average	$\delta^{2}H$-run 1	$\delta^{2}H$-run 2	Average	Tritium (TU)	plus/minus
Upper Calf Creek Spring	-13.70	-13.64	-13.67	-105.4	-106.0	-105.7	2.8	0.25
Lower Calf Creek Spring 1 (East)	-12.50	-12.43	-12.46	-99.2	-98.5	-98.9	0.9	0.25
Lower Calf Creek Spring 2 (West)	-14.22	-14.11	-14.16	-105.9	-103.7	-104.8	<0.7 (app .3)	NR*
Sand Creek Shower Spring	-14.05	-13.99	-14.02	-106.6	-106.5	-106.5	1.4	0.31
Willow Patch Spring	-12.64	-11.83	-12.23	-91.0	-91.3	-91.2	5.4	0.3
Dry Hollow Spring	-12.99	-12.97	-12.98	-104.5	-105.0	-104.7	0.9	0.26
Deer Creek Spring	-12.26	-12.11	-12.18	-97.7	-96.7	-97.2	0.8	0.24
Deer Creek Floodplain Well	-12.93	-12.82	-12.88	-98.5	-100.0	-99.3	<0.5	NR*

*NR=Not Reported by lab.
(-12.64), etc. Being re-run by lab.